NEOTROPICAL BIOLOGY AND CONSERVATION

Neotropical Biology and Conservation
17(1): 29–38 (2022)
doi: 10.3897/neotropical.17.e72273

RESEARCH ARTICLE

Abundance of the Resplendent Quetzal *Pharomachrus mocinno* (Trogoniformes, Trogonidae) in the tourist sector of a cloud forest reserve

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Academic editor: Ana M. Leal-Zanchet | Received 28 July 2021 | Accepted 23 December 2021 | Published 12 January 2022

Citation: García Reynaud JA, Sorto Sabillón ME, Padilla Barahona AF (2022) Abundance of the Resplendent Quetzal *Pharomachrus mocinno* (Trogoniformes, Trogonidae) in the tourist sector of a cloud forest reserve. Neotropical Biology and Conservation 17(1): 29–38. https://doi.org/10.3897/neotropical.17.e72273

Abstract

The Resplendent Quetzal (*Pharomachrus mocinno*) exhibits characteristics that are common to species prone to extinction, such as occurring at low densities, presenting strict ecological requirements, and inhabiting locations with high rates of degradation. The lack of data on the abundance of threatened species makes it difficult to make management decisions and does not allow to know trends over time, which is essential for conservation in their distribution areas. The abundance and density of the Resplendent Quetzal was estimated from audio/visual detections analyzed with distance sampling techniques. Data was collected in the public use sector of La Tigra National Park, a reserve of virgin and secondary growth cloud forest in Honduras, Central America. A population $N = 136$ was found with a density of 40 quetzals per km^2. There are no systematic studies on the population size and density of the species for this site since 1979, in which a population of 145 quetzals was reported. The estimation of the Resplendent Quetzal population for the total area of the park is a main research priority, which will make it possible to evaluate the viability of the species and the establishment of a new baseline for conservation policies and environmental education efforts in the area of influence.

Keywords

charismatic species, conservation, distance sampling, Honduras, La Tigra, population size

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Introduction

The Resplendent Quetzal (*Pharomachrus mocinno* De la Llave, 1832) is a neotropical trogon with high ecological, social and economic relevance at the regional level. Its cultural value dates back to pre-Hispanic history, and the glowing green of its body, luminous red chest, and long upstream coverts in the male of the species are an icon of the cloud forests of Mesoamerica.

The Resplendent Quetzal has a distribution from southern Mexico to western Panama, with two recognized subspecies: *Pharomachrus mocinno mocinno*, in Mexico, Guatemala, El Salvador, Honduras and Nicaragua, and *Pharomachrus mocinno costaricensis*, in Costa Rica and Panama (Solórzano and Oyama 2010; Schulz and Eisermann 2017; Bolaños et al. 2019). Between the two there are different conservation challenges, associated with better management of the southern quetzal habitat and the lack of key data for management decision-making in some regions of its northern distribution.

With regard to the state of the habitat of the species, it is known that between *P.m. mocinno* and *P.m. costaricensis* there is a low, but unique genetic diversity that indicates that there were two large populations of Resplendent Quetzals, reduced in recent years to isolated groups in each country, which consequently highlights the need to establish phylogeographic conservation priorities (Solórzano et al. 2004; Solórzano et al. 2009; Bolaños et al. 2019). It has been proposed that the category of "near threatened" (BirdLife International 2021) in which the species is currently considered, be revised taking into account its presence in only 22 localities with remnants of cloud forest in 7 countries (Solórzano et al. 2003).

Cloud forests are among the most threatened ecosystems in the world, mainly due to the demographic explosion, expansion of the agricultural frontier, and the lack of fire control (LaBastille and Allen 1969; Cruz and Erazo 1977; LaBastille and Pool 1978; Solórzano et al. 2003; Renner and Markussen 2005; Toledo-Aceves et al. 2011). In Central America, deforestation is the major factor in habitat degradation (Renner 2004), and ranges from 0.32 to 0.92% per year; Honduras is the third highest country in terms of its forest loss, reporting a yearly rate of 0.48% (Sesnie et al. 2017), which is particularly important considering that losses of cloud forests from 1970 to 2000 have led to a reduction in the distribution of *P. m. mocinno* by 82%. It has been documented that the change in land use or the reduction of the size of forests have extirpated complete populations, even when the remnants of forests exhibit the minimum size in which quetzals have been registered in the past (Solórzano et al. 2003).

The lack of recent studies concerning the abundance and density of the Resplendent Quetzal is an obstacle to the establishment of conservation priorities. In Honduras, there has not been a systematic study of the species in cloud forest remnants since 1979, therefore, the generation of data on abundance and density is a necessary starting point to interpret population trends, assess conservation values in protected areas, and make it possible to compare populations throughout their distribution.

The conservation of charismatic species such as the Resplendent Quetzal, based on medium and long-term abundance monitoring and the assessment of popula-

tion trends, contributes to the conservation of a high associated biodiversity, taking into account biological aspects of the species such as the migration to lowlands in the non-reproductive season (Powell and Bjork, 1995) and specific resource requirements for nesting and chick rearing, such as decaying trees, common in primary forests, and a healthy fruit population, insects and small vertebrates (Skutch 1944; Hanson 1980; Wheelwright 1983; Ávila et al. 1996).

The aim of this study is to determine the abundance and density of the Resplendent Quetzal in the tourist sector of La Tigra National Park, Honduras, Central America.

Methods

The study was carried out in La Tigra National Park, located in the department of Francisco Morazán, 10 km northeast of the Honduran capital, Tegucigalpa, and established as a protected area by legislative decree in 1980.

La Tigra National Park has a total area of 240.4 km^2 and is part of the Southern Cordillera (Monroe 1968), located between southern Mexico, Guatemala, El Salvador, Honduras and Nicaragua. The park has a core zone of 75.71 km^2 with around 50 km^2 of cloud forest of secondary growth and 10 km^2 of virgin forest, at altitudes between 1800 and 2290 m. The northern and southern sectors of the core zone are divided by an old road, now called Principal trail, formerly used to transport mineral extracted from the area, and encompasses two main types of forests: subtropical humid forest and low montane humid forest, with annual rainfall between 1000 and 2000 mm and predominant vegetation of pine / oak associations, epiphytes and mosses (Cruz and Erazo 1977; Hanson 1980).

The study site in La Tigra National Park comprises the sector of public use with tourist load. The surveyed trails and their length are: La Cascada (2200 m), La Esperanza (2500 m), Jucuara (950 m), Bosque Nublado (1500 m), Principal (990 m) and Granadilla (650 m) (Fig. 1A).

For the detection of birds, each of the six trails was surveyed back and forth at a constant pace, without count points, every month, from June 2019 to June 2020. No playbacks of territorial calls or songs were used. The walks were carried out simultaneously, with a starting time of 0530, by six teams of two observers each.

The size of the population in the area and the density were determined through distance sampling techniques (Buckland et al. 1993) (formula 1):

$$D^{\wedge} = n / (2wL * P_a) \quad (1)$$

Where $D^{\wedge}$ is the estimated density, n is the number of detections, w is the width of the observation band on the side of the trail, L is the total length traveled, and P_a is the detectability.

In order to calculate P_a, the detection function $g(x)$ was estimated, that is, the probability that a quetzal at a distance x from the trail is detected. To estimate $g(x)$, the perpendicular distances of each observed quetzal to the trail were plotted in a

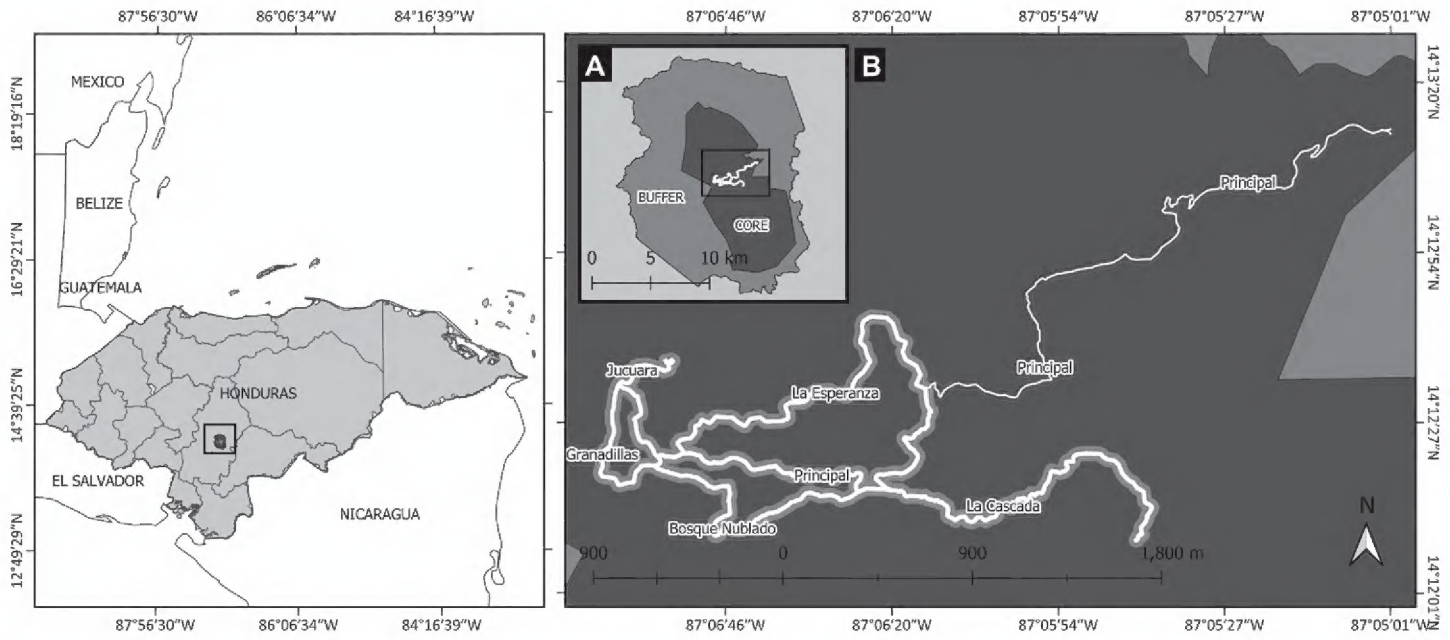

Figure 1. Location of the study area: La Tigra National Park, Honduras: **A** buffer zone and core zone **B** trails of the tourist sector of the park, where the thick white line depicts the surveyed trails and the gray outline depicts the truncation distance of 35 m on each side of the surveyed trails.

histogram, and functions with cosine adjustments for uniform, half-normal and hazard rate models were fitted to the data using the Distance 1.0.2 package of the R 3.3.3 environment (R Development Core team 2018).

Taking into account that a low number of detections would not allow the estimation of $g(x)$ (Thomas et al. 2010), only the data from the 2020 breeding season were used. Months where there were few or even no detection of quetzals, would have no influence on the calculation of the detection function $g(x)$, while generating an increase in the total effort, resulting in negative bias in the density estimate, induced by the lower notoriety and greater dispersion of quetzals in the non-breeding season during incubation, chick rearing and altitudinal migration (Skutch 1944; Hanson 1980; Ávila et al. 1996; Renner 2004). Environmental conditions such as rain can also greatly reduce the detectability of birds (Robbins 1981). For the Resplendent Quetzal, rain reduces the iridescence of its feathers, allowing them to camouflage in the green vegetation brightened by moisture (LaBastille et al. 1972).

In order to reduce bias associated with the possible simultaneous counting of individuals by different teams of observers, a truncation of 35 m was applied to the observations, i.e., no quetzal detected at more than 35 m from the trail was recorded, considering that some segments of Principal and Bosque Nublado trails show a maximum proximity of 100 m (Fig. 1B) where there could be a probability of double counts. Truncating was also intended to reduce the error in estimating distances to faraway detections.

The best-fitting model was selected by evaluating the Akaike's Information Criterion (AIC) (Akaike 1974; Burnham and Anderson 2002) and by the visual analysis of probability detection functions and cumulative distribution functions evaluated under the Cramér-von Mises criterion (Buckland et al. 2001).

The total length traveled during the breeding season was 48,840 m, with a 35 m observation band to each side of the trail, resulting in an area of 3.42 km^2.

Table 1. Number of quetzal individuals detected per month during the survey and replica in the six transects of La Tigra National Park, Honduras. The symbol "-" indicates a month in which it was not possible to visit the site due to national circulation restrictions due to SARS-CoV-2.

	2019							2020						
Trip\Month	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Σ
No. of individuals (survey 1)	2	1	3	5	0	0	3	0	4	-	31	10	29	88
No. of individuals (replica)	3	1	1	2	0	6	0	0	2	-	7	40	5	67
Total of individuals	5	2	4	7	0	6	3	0	6	-	38	50	34	155

Figure 2. **A** male and **B** female Resplendent Quetzal in Bosque Nublado trail of La Tigra National Park, Honduras **C** the pair was observed alternating fruit deliveries into the nest during breeding season.

Table 2. Number of sightings and vocal records of quetzals per trail during breeding season La Tigra National Park, Honduras.

Trail	La Cascada	La Esperanza	Jucuara	B. Nublado	Principal	Granadillas
Elevational range (m)	1888–2162	1975–2176	1879–1951	1941–2138	1914–2157	1886–1913
No. of individuals	12	42	11	21	36	0

Results

A maximum abundance of quetzals at the site was found for the period April - June 2020 (Table 1), corresponding to the breeding season for that year, in which courtship behaviors, nest building, and chick rearing (Fig. 2) were observed. The distribution of observations per trail is shown in Table 2.

The detection functions fitted to the data for the breeding season, i.e., 122 observations for the months April – June, for the cosine adjusted half-normal, uniform, and hazard-rate models, and their goodness of fit results by cumulative distribution functions are shown in Fig. 3.

The detectability, population size, and density values calculated by the model with the lowest AIC (Table 3) were selected, which is the half-normal model with cosine adjustment (Fig. 3A1) (AIC = 868.36 < 868.85 < 869.11). The model suggests that 89% of the quetzals present within 35 m of the trails in the study area were detected during the monthly surveys in the course of the breeding season on the cloud forest reserve.

The evaluation of the goodness of fit (Fig. 3A2–C2) with a Crámer-von Mises value $p = 0.06$ ($p > 0.05$) (Table 3) indicates that the half-normal model with cosine adjustment adequately fits the data. The model calculates a population of 136 quetzals for the studied area. The resulting density of quetzals for the sampled area is 40 quetzals / km^2.

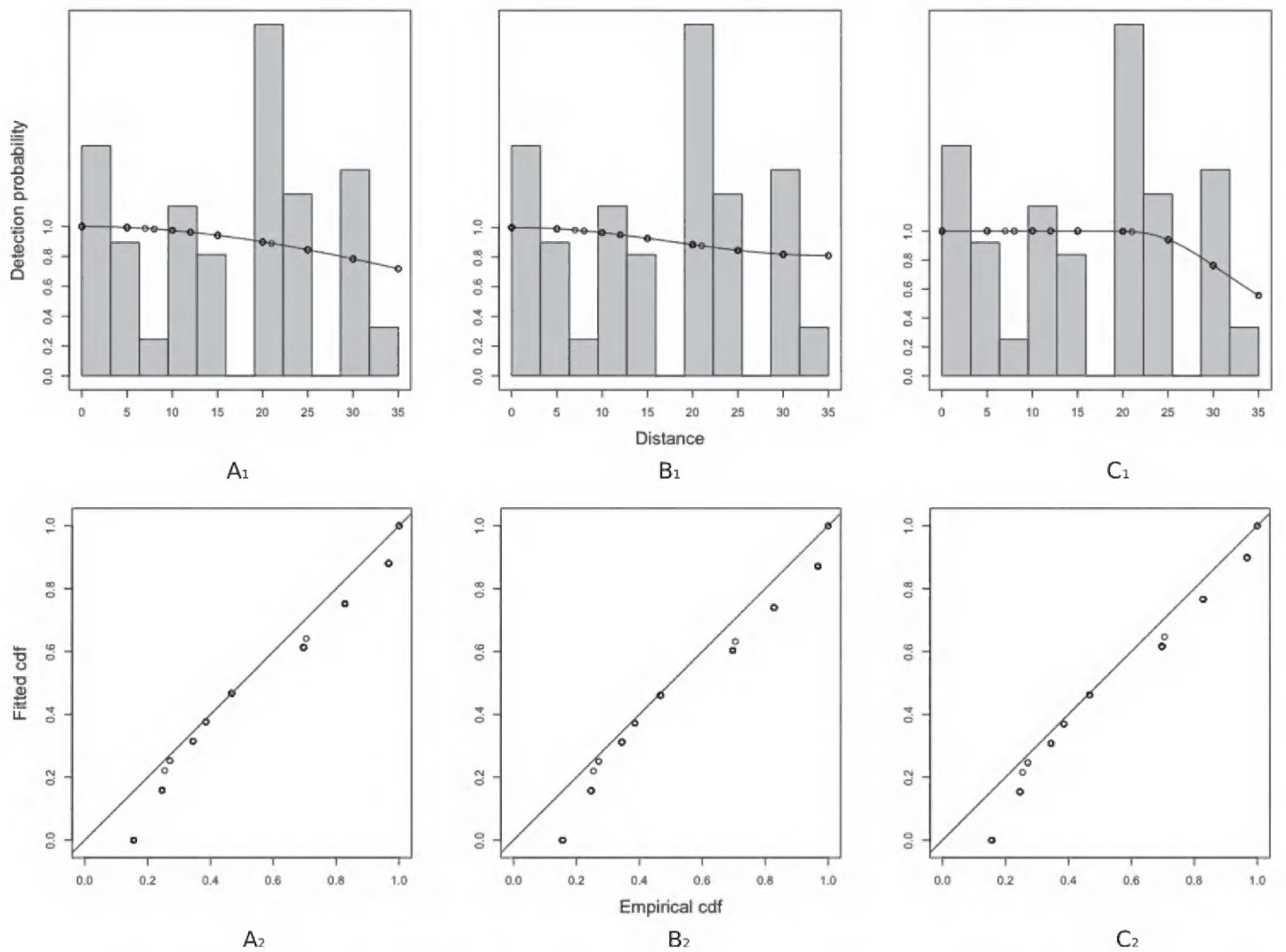

Figure 3. Probability detection functions for cosine adjusted models **A1** half-normal **B1** uniform, and **C1** hazard-rate for the frequency of observations by distance range with truncation at 35 m. Goodness of fit for 122 observations, with roundings in 12 values, for models **A2** half-normal **B2** uniform, and **C2** hazard-rate, with cosine adjustment.

Table 3. Quality estimators, detectability values, population size, and density for each model. AIC: Akaike Information Criterion, P_a: detectability, P_aSE: P_a standard error, P_aCV: P_a coefficient of variation, CvM *p*: Cramér-von Mises criterion *p*-value, *N*: population (individuals), *D*^: density (individuals/km^2).

Model + adjustment	AIC	P_a	P_aSE	P_aCV	CvM *p*	*N*	*D*^
Half-normal, cosine (Fig. 2A1)	868.36	0.89	0.09	0.09	0.06 (Fig. 2A2)	136	40
Uniform, cosine (Fig. 2B1)	868.85	0.91	0.11	0.12	0.07 (Fig. 2B2)	135	39
Hazard-rate, cosine (Fig. 2C1)	869.11	0.93	0.06	0.06	0.07 (Fig. 2C2)	132	39

Discussion and conclusions

A population of 136 Resplendent Quetzals and a density of 40 quetzals / km^2 were calculated in the 3.42 km^2 tourist sector of La Tigra National Park. At a regional level, studies that have carried out censuses, instead of population size estimates from line transects counts, have found for *P.m. mocinno* densities of 15 quetzals / km^2 in 1988 and 18 quetzals / km^2 in 2002 in an area of 1.02 km^2 (Renner 2004) in northern Guatemala and for *P.m. costaricensis*, a density of 44 quetzals / km^2, in an area of 0.07 km^2 in the Monteverde reserve in northern Costa Rica (Powell and Bjork 1995).

There are no known data on the abundance of the Resplendent Quetzal in La Tigra National Park since 1979, when a population of 145 quetzals was reported in the area

that soon afterwards became the tourist sector of the park (Hanson 1980). La Tigra was declared a protected area in 1980, which is a factor that contributed to the stability observed in the species population between 1979 and 2020; however, recent threats in the surroundings of the park and concrete management measures in the area must be evaluated to avoid future reductions in the abundance of the emblematic species.

The Resplendent Quetzal exhibits a set of characteristics that has been identified as common among species prone to extinction, including low population densities, feeding based on irregular resources such as fruit, specialization of diet, and inflexible ecological requirements (LaBastille and Allen 1969; Wheelwright 1983; Solórzano et al. 2009); therefore, it urges the adoption of practices aimed at conserving their vital needs. The genetic diversity of the Resplendent Quetzal, represented by both subspecies requires special conservation efforts with national and international agreements, particularly in the northern region, with notable environmental pressures and higher rates of forest loss (Solórzano et al. 2003; Solórzano et al. 2004; Solórzano et al. 2009).

The low number of observations in the non-breeding season (Table 1) can be attributed to a variety of behavioral, ecological, and environmental factors (Skutch 1944; LaBastille et al. 1972; Hanson 1980; Robbins 1981; Ávila et al. 1996; Renner 2004), among such, the altitudinal migration of the species represents a consequent need to conserve spaces at lower elevations (LaBastille and Pool 1978; Wheelwright 1983; Ávila et al. 1996; Solórzano et al. 2000; Renner 2004). The restoration of a system of forest patches that reestablishes biological corridors (Loiselle et al. 1989; Powell and Bjork 1995; Ávila 1998; Solórzano et al. 2003; Solórzano et al. 2009) could potentially contribute to the conservation of additional species (LaBastille and Allen 1969).

The restoration of non-breeding spaces at low elevations becomes especially important considering the effects of the degradation of pine forests by the southern bark beetle (*Dendroctonus frontalis* Zimmermann, 1868), increase of human settlements, and urbanization in the core zone, buffer zones, and areas immediately surrounding La Tigra National Park (Rivera et al. 2010; Coello-Balthasar et al. 2011; Gomez et al. 2020) that threaten the survival of the species during the altitudinal migration. Factors such as these aggravate the historical threats of La Tigra such as the existence of private lands within the park area, illegal logging, forest fires, and the expansion of the agricultural frontier (Richards 1996; Bonta 2005).

Considering that during the 12 months of observation, quetzals were detected in 5 of 6 trails in the park, the monitoring of reproductive activity and the temporary closure of trails with active nests during the breeding season are recommended. Such management measures could contribute to avoid the disturbance that human transit causes (Skutch 1944; Hanson 1980) in critical processes such as the selection of nests, incubation, and rearing.

As potential sources of bias in this study, using data exclusively from the breeding season in order to obtain a sufficient number of detections, necessary to estimate the detection function $g(x)$, also yields lower precision estimates due to the fact that quetzals are observed in groups rather than dispersed throughout the study area. An additional bias factor is the non-random placement of transects. Given that the objective of the study is to obtain abundance data in the park's tourist load sector,

the trails surveyed for the detection of individuals were the tourist trails. Therefore, although this baseline study allows comparisons of future estimates within the area covered, inferences cannot extend outside the area of the sampled transects.

There is a 100 m proximity between some segments of the trails, notably between the Principal and Bosque Nublado trails, which makes it essential to incorporate field methods such as truncation to reduce the bias related to over estimation due to individuals being counted simultaneously by two teams of observers between nearby trails. In addition, during the months of the study, it was noted that the presence of observers did not generate a response in the quetzals' movements, i.e., the birds weren't driven closer or farther away, therefore, recording the same individuals in more than one trail on a given survey day could be mainly due to non-responsive movement of the quetzals from one trail to another. Non-responsive movement is usually ruled out as a source of bias because random movements tend to generate a balance between animals that were counted due to their movement towards the observer's range, and animals that were not counted due to their movement away from the observer.

The estimation of the Resplendent Quetzal population with representativeness for the total area of the park is a priority research need, which will make it possible to evaluate the viability of the species and the establishment of a new baseline with the potential to implement conservation policies and environmental education efforts in the area of influence.

Acknowledgements

Thanks are extended to all involved in this project: the Institute for Educational and Social Research and Evaluation, INIEES, at UPNFM, for funding this study. Arlon Domínguez, Carlos Valdez, Daniel Sabillón, David Cáceres, Edy Rivera, Jimena Nolasco, Julissa Enamorado, Luis Jarquín, Stheffania Nasser, Richard Vásquez and Don Chico for all the effort during the field data collection. AMITIGRA foundation and Jorge Luis Murillo for providing the conditions for the comfort of the team. To Professors Sherry Lyn Thorn, Eric Rexstad, Stephen Buckland and Bianca Bosarreyes for being always willing to answer questions in their respective fields.

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